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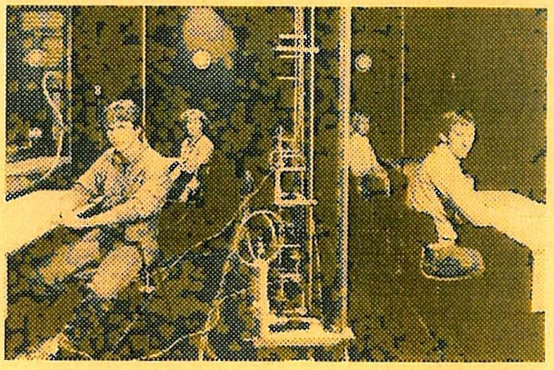

*P. V. Nielsen*

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# The Importance of a Thermal Manikin as Source and Obstacle in Full-Scale Experiments

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# The Importance of a Thermal Manikin as Source and Obstacle in Full-Scale Experiments

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## INTRODUCTION

The thermal manikin is normally introduced at indoor environmental measurements to obtain detailed information on thermal comfort and air quality around a person. This paper deals with the opposite situation where manikins are introduced as sources and obstacles in order to obtain reasonable boundary conditions in experiments with the indoor environment. In other words, how will people influence the surroundings instead of how will the surroundings influence people? The use of thermal manikins in an experiment will of course take both situations into account, however, in some experiments the manikins are used mainly as sources and obstacles.

A person will influence the indoor environment due to heat transfer by conduction, free and forced convection, radiation and latent heat loss. The person is also an emission source of $CO_2$ , water vapour, tobacco smoke and bioeffluent. Finally, a person will influence the room air movement due to flow resistance of the body and body movement, Brohus (1997). A manikin should be able to simulate those effects in situations where they are important for the final flow in the room.

The paper shows examples from displacement ventilation and mixing ventilation separately because the physical process in the two air distribution principles is different. Examples of the use of manikins in experiments with local ventilation will also be given in the last section of the paper.

## DISPLACEMENT VENTILATION

Thermal radiation plays an important role in the heat flow process in a room ventilated by displacement ventilation. Therefore, it is important to use heat sources similar to persons in experiments with this type of ventilation. Figure 1 shows the vertical temperature gradient for different heat sources. The point heat source is a small cylindrical heater with open heating elements, 0.3 m × 0.1$^ø$ m. The thermal manikin is a black painted cylinder with the dimensions 1.0 m × 0.4$^ø$ m.

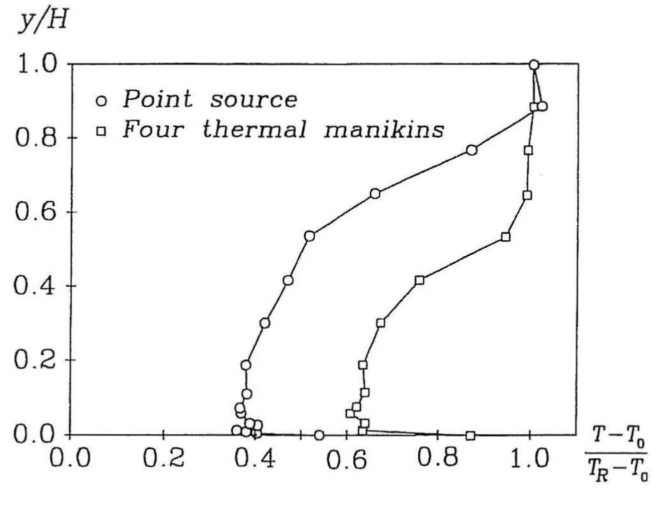



**Figure 1**. Vertical temperature gradients in a room with different heat sources. Nielsen (1993).

The location of the normalized temperature gradients in figure 1 depends on the size and temperature of the heat source. A heat source as the point source will give a temperature distribution with relatively low temperatures in the occupied zone in comparison with the temperature in the return flow. Four thermal manikins generate a temperature distribution with a high level in the occupied zone and it is obvious from figure 1 that it is impossible to use small point sources as person simulators in experiments with displacement ventilation.

The ratio of radiation to convection is an important parameter. A low ratio will displace the curves to the left because it will decrease the amount of heat supplied to the floor. Experiments with four thermal manikins (1.0 m × 0.4° m) support this theory. Figure 2 shows how the vertical temperature profiles are displaced to the left-hand side of the figure when the emission is decreased. The low emission is obtained by covering the cylinders with aluminium foil, and the high emission (0.95) is obtained in the standard situation where the cylinders are painted black.

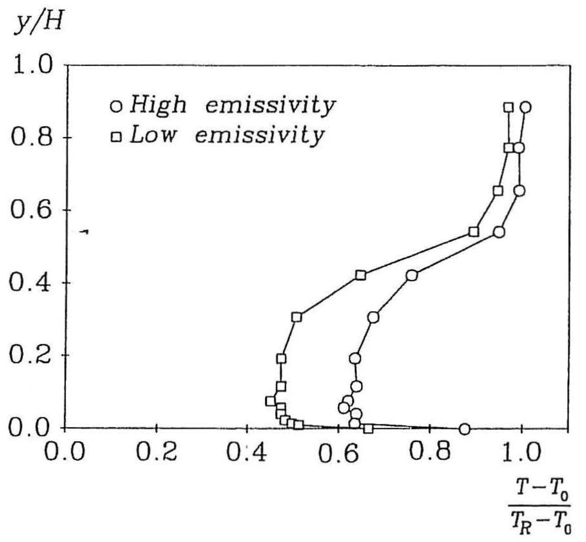



**Figure 2**. Vertical temperature gradients in a room with four thermal manikins which have a high and a low emissivity, Nielsen (1996).

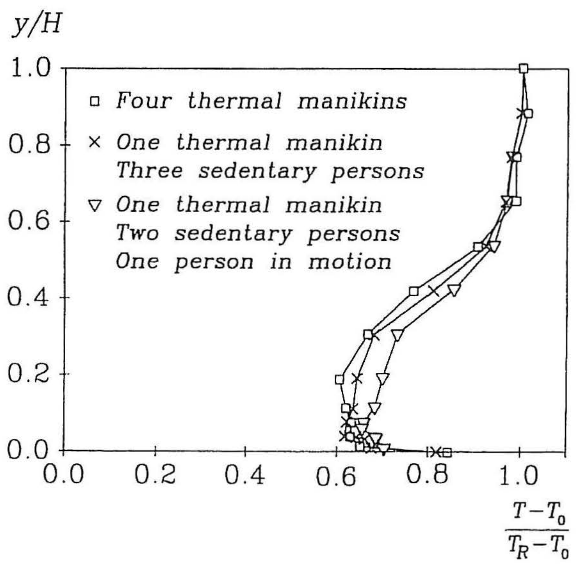



**Figure 3**. Vertical temperature gradients in a room with thermal manikins, sedentary persons and people in motion, Nielsen (1993).

Figure 3 shows the vertical temperature distribution in a room with thermal manikins and persons. The manikins seem to give a sufficiently thermal description of a person. It is especially important to notice that a moving person is unable to break the stratification and that the measurements show only a slight reduction in the effectiveness of the system. Other measurements made during great activity, and with an open door to the test room, do also confirm the stability of the stratified flow in the room.

Vertical concentration gradients in a room ventilated by displacement ventilation are influenced by people in motion as shown by Brohus and Nielsen (1994) and later in greater detail by Bjørn et al. (1997).

Exhalation is an important contaminant source when problems like passive smoking are considered. Bjørn and Nielsen (1996) have shown that the exhalation from a breathing thermal manikin will be concentrated in a horizontal layer with very high concentration, up to five times the fully mixed value for temperature gradients larger than 0.5°C/m.

## MIXING VENTILATION

Mixing ventilation is controlled by the momentum flow from the supply opening contrary to displacement ventilation where buoyancy and free convection are the main forces in the flow. The temperature distribution will therefore not be strongly influenced by the type of heat load, but the following experiments show that the velocity level and the maximum velocity in the room are influenced by people in the room.

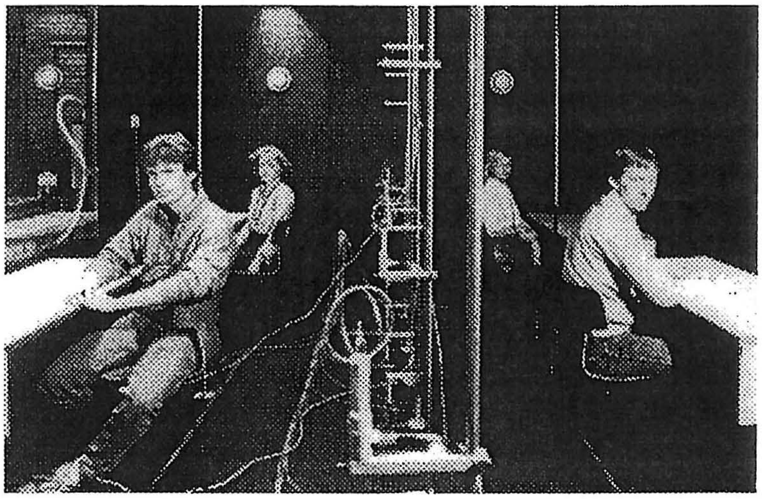


**Figure 4**. Full-scale room ventilated by mixing ventilation. Experiments with the influence of furniture, heat load and people.

Figure 4 shows a full-scale room installed with mixing ventilation. The maximum velocity in the occupied zone is measured at different air change rates in an empty room both without heat load and with a heat load of 600 W. The maximum velocity is also measured with furniture in the room and with furniture and people.

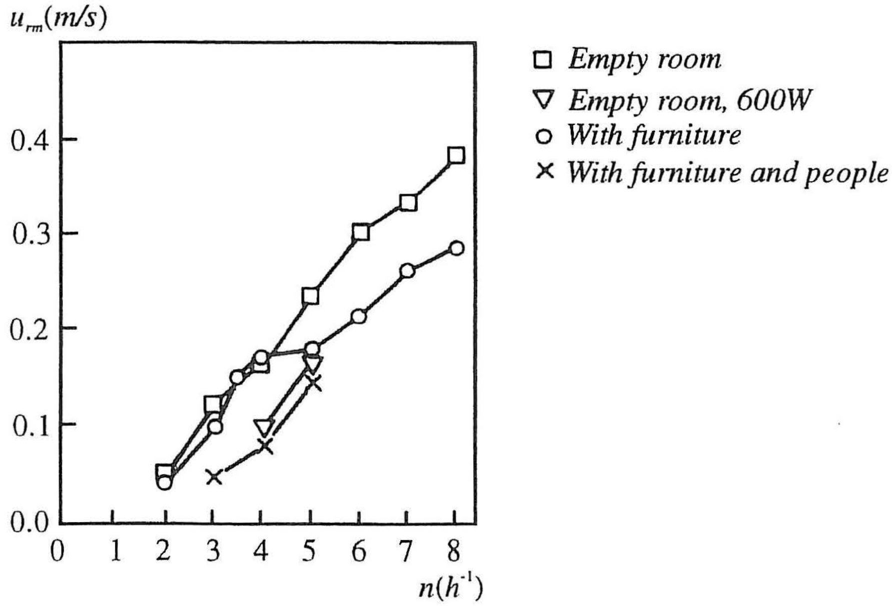



**Figure 5**. Maximum velocity in the occupied zone of a room versus air change rate.

The maximum velocity $u_{rm}$ is linear proportional to the air change rate $n$ for $n > 5$ due to the presence of a fully developed turbulence. Both the furniture and a heat load of 600 W will reduce the velocity level, see figure 5, Heiselberg and Nielsen (1988). Four people in the room, as shown in figure 4, will reduce the velocity to the level obtained in an empty room with a heat load, but it is not possible to decide if this effect mainly is due to heat emission from people in the room or if it is due to restriction of the flow. Experiments by Nielsen et al. (1997 and 1998) show that obstacles as furniture and cold manikins will reduce the maximum velocity in the occupied zone of a room ventilated by mixing ventilation.

## LOCAL VENTILATION

It is often necessary to use thermal manikins in experiments with local ventilation because the size and heat emission from a person will be an important part of the whole process.

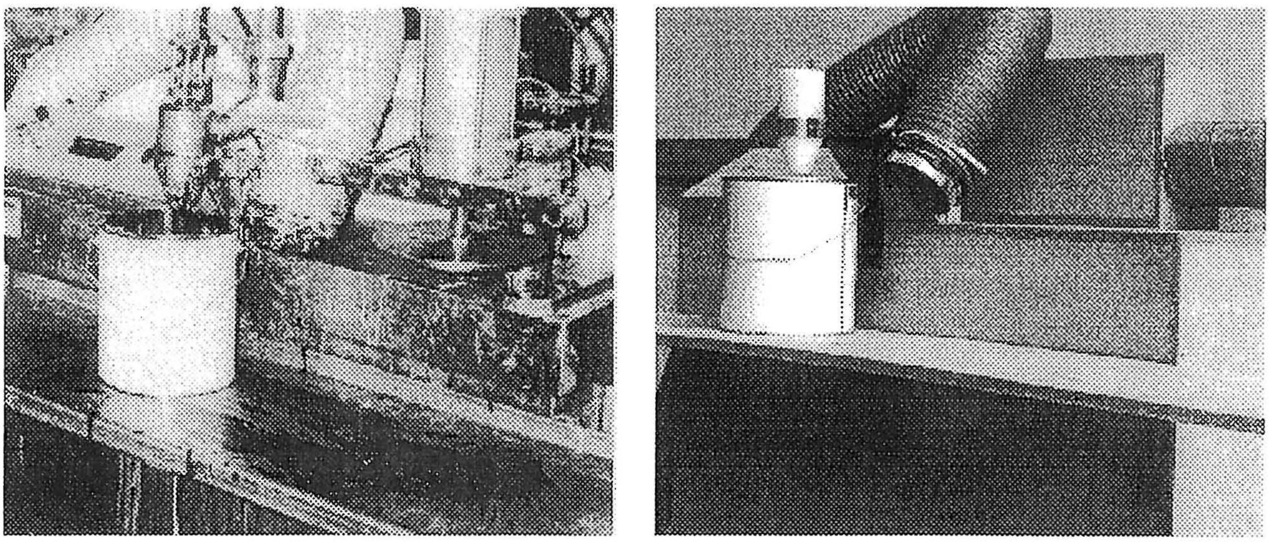
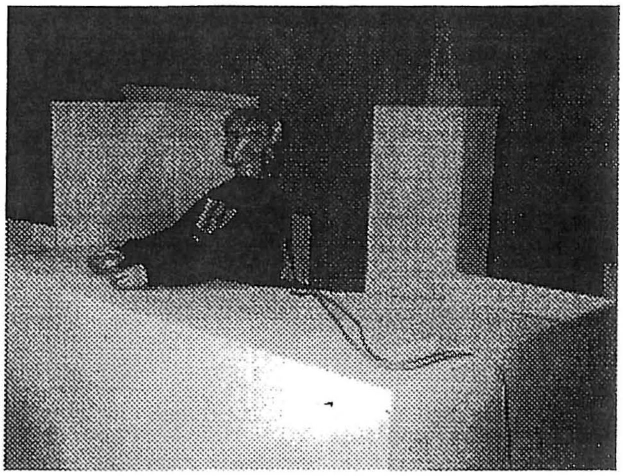


**Figure 6**. Filling machine from the paint industry and a full-scale model.

Experiments with an exhaust system on a full-scale model of a filling machine from the paint industry show that the use of a manikin has some significance. It was expected that the thermal boundary layer from the manikin would transport the contaminant away from the exhaust opening but the measurements show that the capture efficiency was slightly increased, probably due to a reduction of the flow area in front of the exhaust opening which causes an increase in the velocity level.

The experiment does not include the registration of personal exposure. However, new types of manikins with breathing functions are able to register these data.



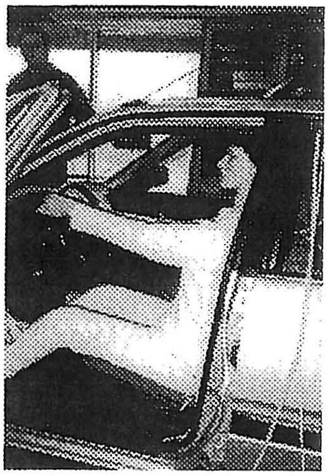


**Figure 7**. Determination of the comfort level at a checkout assistant's working area and in a car.

Figure 7 shows two examples of experiments where thermal manikins are a necessary part of the set-up. The manikins are both used for measuring the comfort level and they do also serve as thermal load on the surroundings because in those situations the heat output from a person will influence the local temperature distribution.

## CONCLUSION

The paper shows several examples where thermal manikins are important as necessary boundary conditions in the experiments. The flux of thermal radiation and free convection, exhalation and body movement are important in displacement ventilation, while thermal plumes and flow resistance are important in mixing ventilation. The geometry of the manikins and the heat output will always be important when experiments are performed within limited spaces, and the use of thermal manikins should be considered in all types of experiments.

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